

# Risk Evaluation Accuracy Using Telematics and Policyholders' Coverage Selection: An Analysis Based on an Equilibrium Model

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## Abstract

This study aims to demonstrate the effect of accurate risk evaluation by Insurtech on the participants' selection of insurance coverage, based on the canonical separating market equilibrium model. A precise risk evaluation through telematics will promote market efficiency by alleviating adverse selection and moral hazard of insureds. In reality, however, risk evaluation is not perfectly accurate even utilizing telematics and thus a certain cross-subsidy applies. The analysis reveals that low-risk individuals tend to purchase less coverage in case a cross-subsidy factor is embedded based on a constant ratio. Meanwhile, when cross-subsidy is factored into the premiums at a constant value, individuals are willing to be fully insured regardless of their risk characteristics.

Keywords: Risk evaluation, Insurtech, Telematics, Separating market equilibrium, Cross-subsidy

## 1. Introduction

Development of information technology permits the banking and security sectors to access new data sources and Big Data, artificial intelligence, cognitive computing, and predictive modeling, leading to a noticeable impact on financial operations; this value chain innovation is known as Fintech. The insurance sector is also increasingly impacted by a similar trend, and it has become recognized as Insurtech. This evolution is impacting every process of insurance operations, including product design, pricing, underwriting, marketing, distribution, and claims management.<sup>1)</sup> Digitalization helps insurers design and price their insurance products; the growing proliferation of new data about insureds, collected via sensors and smart devices permits more granular underwriting of individual risks. Further, sophisticated analytics and predictive modeling connected with telematics devices allow insurers to

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This study is financially supported by Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (C), No. 17K04018, and is based on the presentation at the Asia-Pacific Risk and Insurance Association 2019 Annual Conference. The author appreciates all valuable comments provided by the conference participants.

1) Swiss Re Institute (2017), pp.1-3

create insurance products and set premium rates based on accurate data relating to insureds' behavior rather than inaccurate risk factors such as age, gender, or profession.

For example, insurers are introducing new automobile and medical insurance products utilizing telematics and wearable devices, which helps insurers continuously monitor insureds' behavior by collecting data on aspects such as real-time driving mileage, driving area and time, walking distance, and personal fitness. Development of telematics and sensor-based pricing enables insurers to evaluate risk characteristics of exposures more accurately and to offer more segmented insurance coverage to individual applicants, using a risk-differentiated base. Consequently, insurers have to make decisions on how much they should individualize insurance coverage and price based on risk characteristics, considering the cost of underwriting and maintaining such insurance contracts. Policymakers should also design regulations on insurance premium rates and product development such that they preserve and support insurance availability. The extant literature on insurance, however, has not fully elucidated how Insurtech products and insurance regulations should be designed. Attempting to address this absence in the literature, this study focuses on the utility effects of accurate risk evaluation and analyzes the individuals' choice of insurance coverage based on the separating market equilibrium model.

## 2. Literature Motivating the Study

### (1) Separating Market Equilibrium Model of Insurance

Many studies have theoretically and empirically analyzed the effect of risk classification in the private insurance market long before Insurtech products were introduced. Rothschild and Stiglitz (1976) constructed the separating market equilibrium model of insurance by expanding upon the precedent study by Arrow (1963).<sup>2)</sup> They demonstrated a cost-effective process of categorizing applicants according to their risk character through self-selection when a variety of insurance coverage and premium options are offered by an insurer. This first model, however, was premised on a single-period contract and ignored the existence of competitors; thus, successive studies, including Wilson (1977) and Hoy (1982), refined the model by factoring the possibility of multi-period contracts and a competitive market environment.<sup>3)</sup> Particularly, Hoy (1982) analyzes the cream-skimming mechanism and discussed that insurers may offer a combination of insurance coverage and premium that attracts low-risk individuals only, and they may selectively underwrite such preferable applicants in a cost-effective manner, resulting in undermined insurance availability and excessive risk segmentation

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2) Rothschild and Stiglitz (1976), pp.629-649, Arrow (1963), pp.941-973.

3) Wilson (1977), pp.167-207. Hoy (1982), pp.321-336.

regardless of cost.

## (2) Risk Classification in the Insurance Market

The effect of risk classification in the insurance market has been investigated based not only on the equilibrium model but also on other approaches. Harrington and Doepinghaus (1993) applied the hypothetical compensation model to test the accuracy of risk classification. According to their analysis, the utility for low-risk individuals increases by risk classification but that increase would be less than the utility loss for high-risk individuals because the cost of risk evaluation limits the premium discount, resulting in efficiency loss in the insurance market.<sup>4)</sup>

Crocker and Snow (1986) factored expense loadings into the actuarially-fair separating premiums and showed that the utility gain is obfuscated by the presence of risk evaluation costs.<sup>5)</sup> Hoy (2006) analyzed the utility effect of a risk classification ban through regulatory intervention and indicated that intensified adverse selection would undermine market efficiency unless the number of high-risk exposures in the insurance contract portfolio was low.<sup>6)</sup> Recent contributions utilizing the market equilibrium model include Dionne and Rothschild (2014), who indicated that any insurance applicants would willingly pay fair insurance premiums based on their risk and opt for full insurance coverage in case there was no information asymmetry between the insurer and the applicant.<sup>7)</sup> Their findings imply that Insurtech can help an individual choose sufficient insurance coverage regardless of risk characteristics as long as the insurer can accurately monitor the insured's behavior without any costs.

## (3) Telematics and Risk Evaluation

After telematics automobile insurance was introduced in the early 2000s, it began to attract both academic and practical interest. Edlin (2003) and Litman (2005) both mention that insurance telematics reduces unnecessary automobile driving but simultaneously impairs insurance availability for high-risk drivers.<sup>8)</sup> Suzawa (2008) demonstrated that telematics can mitigate the negative effect of adverse selection and moral hazard while it may impose a cost burden on both policyholders and insurers.<sup>9)</sup> Suzawa (2018) expanded the study to include medical insurance with wearable devices, and discussed the possibility that inaccuracy in determining risk evaluation and monitoring costs would reduce the

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4) Harrington and Doepinghaus (1993), pp.59-84.

5) Crocker and Snow (1986), pp.321-344.

6) Hoy (2006), pp.245-269.

7) Dionne and Rothschild (2014), pp.184-221.

8) Edlin (2003), pp.53-82, Litman (2004), pp.35-53.

9) Suzawa (2008), pp.31-49.

efficacy of Insurtech.<sup>10)</sup> The precedent literature, however, has not elaborated on the effect of telematics on the policyholders' choice of insurance coverage thus far. The following sections, therefore, analyze the effect of accurate risk evaluation by Insurtech on the participants' selection of insurance coverage, by expanding the canonical separating market equilibrium model that focuses on the utility change among individuals.

### 3. Analytical Approach

The analysis is based on the standard separating market equilibrium model of insurance, which has been employed by many studies, as referred to in the previous section. The model presumes some settings, as follows:

- (i) The policyholder holds initial wealth of  $W$  in the no-loss state:  $S_1$ , and she incurs a loss of  $D$  (i.e., the wealth becomes  $W-D$  in the loss state  $S_2$ ).  $D$  is parity among all policyholders.
- (ii) The probability of loss varies among individual policyholders, indicated as  $p_i$  for policyholder  $i$ .

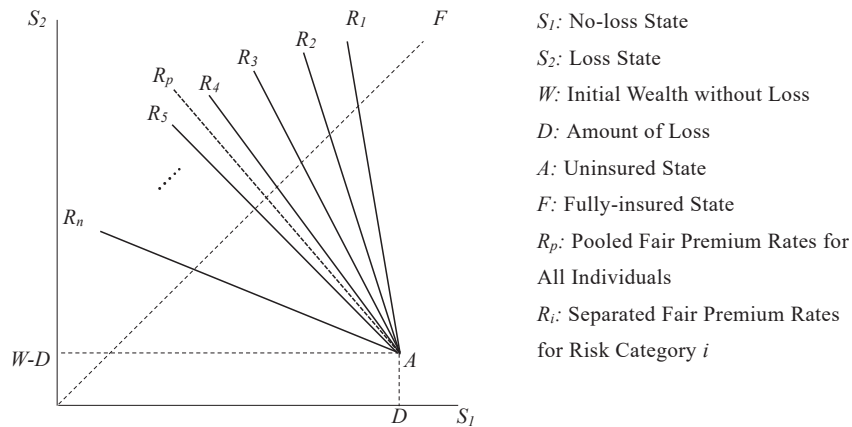


Figure 1. Fair Price of Separating Premium Rates

#### (1) Actuarially-Fair Premium Rates

Figure 1 graphically illustrates the model laid out on the  $S_1$ - $S_2$  plane where Point  $A$  and Line  $F$  denote the uninsured state and fully-insured state, respectively. Insurance coverage is offered by private insurers with a variety from partial to full coverage options, from  $A$  to  $F$ . The insurer is risk-neutral and charges premium rates that depend on the expected loss ( $p_i D$ ) and the coverage ratio chosen by the

10) Suzawa (2018), pp.79-100.

policyholder ( $r_i$ ). When the insurer classifies policyholders into  $n$  groups according to the probability of loss ( $p_i$ ), the actually-fair premiums rates ( $R_i$ ) are defined as:

$$R_i = p_i r_i D, \text{ where } p_1 < p_2 < p_3 < \dots < p_n$$

This is illustrated as a straight line from Point  $A$  to Line  $F$  with a coefficient  $p_i(1-p_i)$ , as illustrated in Figure 1. The insurer breaks even by providing coverage along Line  $R_i$ , or can make a profit if the coverage offered is under that line.

## (2) Expected Utility of Policyholders

The expected utility of policyholders depends on the initial wealth ( $W$ ), the wealth in the loss-state ( $W-D$ ), and the probability of loss ( $p_i$ ). Assuming that policyholders are economically rational and risk-averse, they prefer more generous and less expensive coverage, which means the option of insurance coverage falls in the upper right section above the  $S_1$ - $S_2$  plane. The indifference curve of expected utility is described as a negatively sloped curve from the upper left to the lower right section of the plane. Expanding upon the definition provided by Hoy (2006) and Dionne and Rothschild (2014),<sup>11)</sup> the expected utility of an uninsured individual is derived as follows:

$$U(W, W-D, p_i) = (1-p_i)u(W) + p_i u(W-D)$$

In case an individual purchases an insurance policy with a coverage ratio of  $r_i$ , she will receive an insurance payment of  $r_i D$  when a loss occurs. The wealth in the no-loss state ( $W_1$ ), that at loss-state ( $W_2$ ), and the expected utility ( $U$ ) are defined as follows:

$$\begin{aligned} W_1 &= W - p_i r_i D; W_2 = W - p_i r_i D - D + r_i D \\ \Rightarrow U(W_1, W_2, p_i) &= (1-p_i)u(W - p_i r_i D) + p_i u(W - p_i r_i D - D + r_i D) \end{aligned}$$

The indifference curve of the policyholder's expected utility is identified by taking the derivative with respect to the summation of expected utility of the no-loss and loss states:

$$U_i: \partial W_1 / \partial W_2 = -[p_i \partial U / \partial (W - p_i r_i D)] / [(1-p_i) \partial U / \partial (W - p_i r_i D - D + r_i D)]$$

11) Hoy (2006), pp.248-249, Dionne and Rothschild (2014), p.187.

This is described as a convex curve toward the starting point as  $U_i$  in Figure 2. Reflecting the probability of loss (i.e.,  $p_1 < p_2 < p_3 < \dots < p_n$ ), the indifference curve of a lower-risk policyholder is steeper than that of a high-risk one. Among a variety of coverage options the insurer offers on or under the actuarially-fair premium line  $R_i$ , an individual opts for single insurance coverage to maximize her utility through the trial-and-error process on or over her own expected utility indifference curve  $U_i$ .

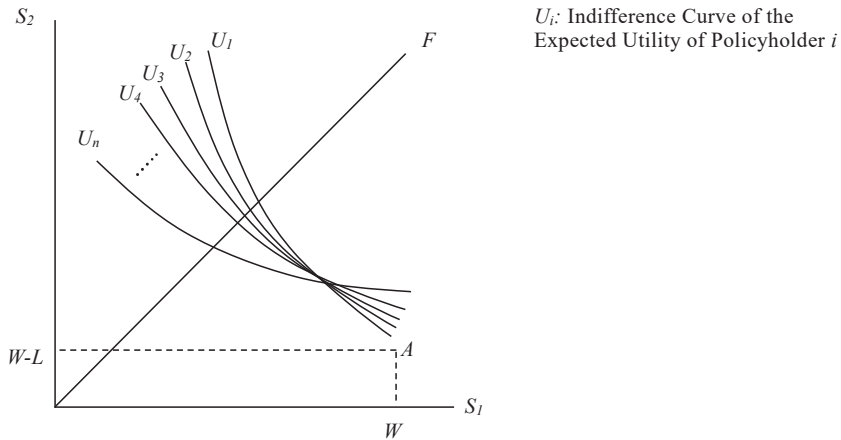


Figure 2. Indifference Curve of Pension Participants

#### 4. Canonical Implications from the Separating Equilibrium Model

The comparative utility approach has often been employed in relation to risk classification issues and rate-making regulatory designs in the insurance market.<sup>12)</sup> The standard model implies that an individual will opt for full insurance coverage through the self-selection process as long as the insurer perfectly evaluates his risk level in a costless manner. Similarly, in case Insurtech allows the insurer to precisely evaluate the risk of each exposure and to provide him with an insurance policy at actuarially-fair premiums, the policyholders—regardless of their risk characteristics—are expected to purchase full insurance coverage and to minimize the basis risk.

In order to derive this expectation from the model, the following additional setting is configured for simplification:

12) Studies that employed the comparative utility approach include Hoy (2006) and Dionne and Rothschild (2014), referred to in section 2.

(iii) There are only two types of individuals with respect to risk: low-risk and high-risk (denoted as type  $L$  and type  $H$ ), and both types are composed of exactly the same number of individuals.

The premium rates applied to high-risk and low-risk individuals ( $R_L$  and  $R_H$ , respectively) are derived as follows:

$$R_L = p_L r_L D, R_H = p_H r_H D, \text{ where } p_L < p_p < p_H, 0 < r_L < 1, 0 < r_H < 1$$

$R_L$  and  $R_H$  become symmetrical lines centering the pooled premium rates line ( $R_p$ ) on the  $S_1$ - $S_2$  plane as illustrated in Figure 3, because both age types consist of the same number of participants. The insurance coverage is offered on or under  $R_L$  for the low-risk type and on or under  $R_H$  for the high-risk type.

The indifference curves for both risk types are also described on the  $S_1$ - $S_2$  plane, and are given, respectively, as:

$$U_L: \partial W_1 / \partial W_2 = -[p_L \partial U_L / \partial (W - p_L r_L D)] / [(1 - p_L) \partial U_L / \partial (W - p_L r_L D - D + r_L D)]$$

$$U_H: \partial W_1 / \partial W_2 = -[p_H \partial U_H / \partial (W - p_H r_H D)] / [(1 - p_H) \partial U_H / \partial (W - p_H r_H D - D + r_H D)]$$

Reflecting the different probability of loss for both risk types,  $U_L$  is described as a steeper curve than  $U_H$  as shown in Figure 3, and an individual chooses a coverage option located on or over his own expected utility indifference curve. Consequently, the wealth in the no-loss state ( $W_1$ ), that in the loss state ( $W_2$ ), and the expected utility for both risk types ( $U_L$ ) and ( $U_H$ ) are defined as follows:

$$W_1 = W - p_L r_L D, W_2 = W - p_L r_L D - D + r_L D$$

$$\Rightarrow U_L(W_1, W_2, p_L) = (1 - p_L) u(W - p_L r_L D) + p_L u(W - p_L r_L D - D + r_L D)$$

$$W_1 = W - p_H r_H D, W_2 = W - p_H r_H D - D + r_H D$$

$$\Rightarrow U_H(W_1, W_2, p_H) = (1 - p_H) u(W - p_H r_H D) + p_H u(W - p_H r_H D - D + r_H D)$$

$U_L$  and  $U_H$  are both maximized when  $r_L = 1$  and  $r_H = 1$  because all actuarially-fair premium rates ( $R_L$  and  $R_H$ ) are defined depending on the probability of loss ( $p_L$  and  $p_H$ ). Low-risk individuals opt for insurance coverage on Point  $O_L$  and high-risk ones do so on Point  $O_H$ ; both are on Line  $F$ , denoting full insurance coverage. As far as Insurtech perfectly complements the information asymmetry between the insurer and the policyholder, individuals regardless of risk type willingly purchase a full coverage option at actuarially-fair premium rates and thus will not be exposed to basis risk.

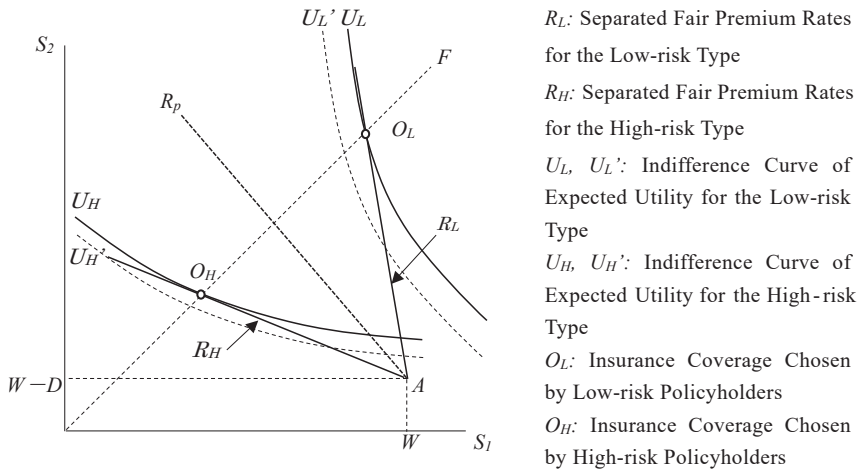


Figure 3. Policyholders' Choice under Perfect Information

### 5. Policyholders' Choice under Imperfect Information

Insurtech will obviously help insurers collect a large amount of risk-related data in real time and evaluate risk individual exposures more precisely. However, currently, data collected through telematics or wearables are limited to driving mileage, the insured's whereabouts, and walking distance. These factors are correlated with the frequency and severity of automobile accidents, injury, or illness, but do not perfectly represent the expected loss. In addition, regulations may prohibit the usage of certain sorts of risk factors because of privacy and social acceptability reasons. The residual information imperfection and asymmetry still exist and the cross-subsidy is allowed even for Insurtech products. Thus, we must consider other cases where an insurer cannot perfectly evaluate the risk of each exposure and premium rates are applied on the partially cross-subsidized base.

#### (1) Cross-Subsidy Factor with Constant Ratio

First, consider a case where the cross-subsidy factor  $s$  is a constant ratio of actuarially-fair premiums; the premiums for low-risk individuals are increased and those for high-risk ones are discounted from the actuarially-fair premium rates. The premium rates charged from the low-risk and high-risk policyholders are defined as  $p_L r_L D(1+s)$  and  $p_H r_H D(1-s)$ , respectively. Thus,  $W_1$  and  $W_2$ , as well as  $U_L$  and  $U_H$  are defined as follows:



$$W_1 = W - p_L r_L D(1+s), W_2 = W - p_L r_L D(1+s) - D + r_L D$$

$$\Rightarrow U_L(W_1, W_2, p_L) = (1-p_L)u[W - p_L r_L D(1+s)] + p_L u[W - p_L r_L D(1+s) - D + r_L D]$$

$$W_1 = W - p_H r_H D(1-s), W_2 = W - p_H r_H D(1-s) - D + r_H D$$

$$\Rightarrow U_H(W_1, W_2, p_H) = (1-p_H)u[W - p_H r_H D(1-s)] + p_H u[W - p_H r_H D(1-s) - D + r_H D]$$

From the definitions where  $s > 0$ , the expected utility of a low-risk individual  $U_L, U_L'$  is maximized when  $r_L < 1$ , and  $r_L$  chosen by the policyholder decreases as  $s$  increases. The more the cross-subsidy that is factored into the premiums, the less is the insurance coverage the low-risk person chooses. In the meantime, the expected utility of a high-risk individual ( $U_H, U_H'$ ) is maximized when  $r_H \equiv 1$ , which means high-risk individuals willingly purchase an insurance product at full or close-to-full coverage. This is observable in Figure 4 where the premium rates ( $R_L'$  and  $R_H'$ ) shift inward from the original actuarially-fair premium lines round on Point A, indicating  $s$  with a positive value. The indifference curve of expected utility of low-risk policyholders ( $U_L$ ) is at the highest position at Point  $O_L'$ , which is under Line  $F$  denoting partial insurance coverage, while  $U_H$  is the highest at  $O_H'$  and a high-risk person chooses full insurance coverage.

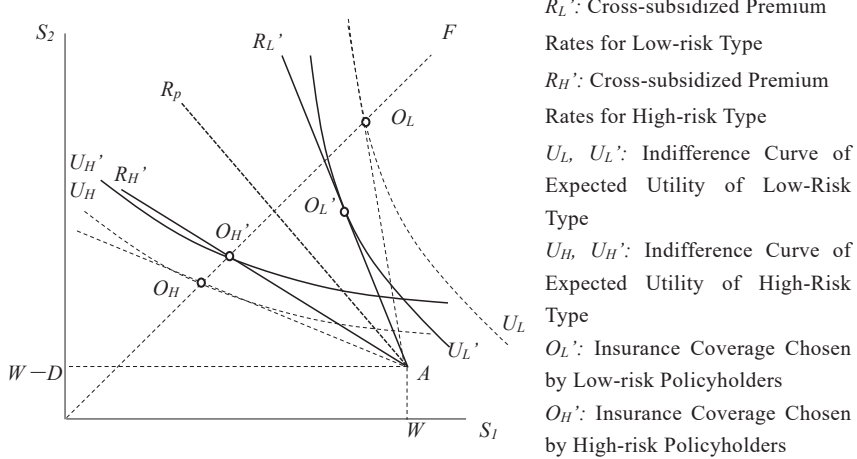


Figure 4. Cross-Subsidy of Constant Ratio and Policyholders' Coverage Selection

## (2) Cross-Subsidy Factor with Constant Value

Consider another case where the cross-subsidy factor  $s'$  is a constant value and is factored into actuarially-fair premium rates; the premium rates charged from the low-risk and high-risk policyholders are defined as  $(p_L r_L D + s')$  and  $(p_H r_H D - s')$ , respectively.  $W_1$  and  $W_2$  as well as  $U_L$  and  $U_H$  are derived as:

$$\begin{aligned}
 W_1 &= W-(p_L r_L D+s'), W_2 = W-(p_L r_L D+s')-D+r_L D \\
 &\Rightarrow U_L(W_1, W_2, p_L) = (1-p_L)u[W-(p_L r_L D+s')] + p_L u[W-(p_L r_L D+s')-D+r_L D] \\
 W_1 &= W-(p_H r_H D-s'), W_2 = W-(p_H r_H D-s')-D+r_H D \\
 &\Rightarrow U_H(W_1, W_2, p_H) = (1-p_H)u[W-(p_H r_H D-s')] + p_H u[W-(p_H r_H D-s')-D+r_H D]
 \end{aligned}$$

The high-risk individual still opts for full or close-to-full insurance coverage because  $U_H, U_H''$  is maximized when  $r_H \cong 1$ . As for the low-risk individual under this condition, the expected utility  $U_L, U_L''$  can be also maximized when  $r_L \cong 1$ . In addition,  $r_L$  chosen by the policyholder is unaffected by the value of  $s'$ . The premium rates for both risk types ( $R_L'$  and  $R_H'$ ) make a parallel shift from the actuarially-fair premiums as described in Figure 5 because  $s'$  is a constant positive value. The indifference curves of expected utility of low-risk and high-risk persons ( $U_L''$  and  $U_H''$ ) both trace the highest curve via Point  $O_L''$  and Point  $O_H''$  on Line  $F$  denoting full insurance coverage. It is implied, from the analysis, that policyholders are willing to pay cross-subsidized premium rates to purchase full insurance coverage as long as the cross-subsidy factor is embedded on a constant-value base.

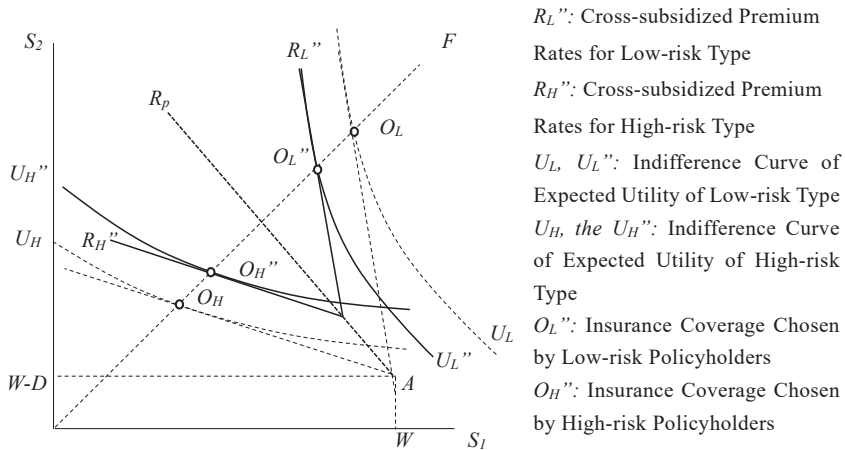


Figure 5. Cross-Subsidy of Constant Value and Policyholders' Coverage Selection

### 6. Summary and Implications

Insurtech is significantly impacting the insurance industry and is engendering innovation in product development, pricing, and underwriting. By utilizing telematics and wearable devices, insurers can evaluate the risk characteristics of insured exposures and re-classify those exposures more precisely than in the case of traditional insurance contracts. Insurtech is thus expected to address

information asymmetry relating to the risk attribute and contribute to alleviating adverse selection and moral hazard. In reality, however, data on risk factors collected through Insurtech are limited; such risk factors include the driving area, time and mileage for automobile insurance, the insured's whereabouts, and walking distance for medical insurance. Therefore, risk evaluation is not yet precise at present, and cross-subsidy is factored into the premium rates; low-risk policyholders are imposed with a surcharge in addition to the actuarially-fair separating premiums, and high-risk policyholders can avail a discount with regard to separating premiums.

This study analyzes how the policyholder's choice of insurance coverage will be affected by the accuracy or inaccuracy of risk evaluation using Insurtech, based on the separating equilibrium model of the insurance market. The analysis reveals that low-risk policyholders tend to opt for partial insurance coverage in a case where the cross-subsidy factor is embedded as a constant ratio of actuarially-fair premiums. In addition, the more cross-subsidy a factor has, the less is the insurance coverage low-risk policyholders choose; as a result, they may be exposed to significant basis risk. The analysis also demonstrates that policyholders are willing to be fully insured regardless of risk characteristics when the cross-subsidy is factored into actuarially-fair premium rates as a constant value. These results will help insurance industry managers to design the premium rates structure of Insurtech products using a constant-value cross-subsidy base in order to attract all potential policyholders regardless of their risk characteristics in a cost-efficient manner. The study also provides information for insurance policymakers about the regulatory framework pertaining to insurance ratemaking. Risk classification with a cross-subsidy on a constant-ratio base should be banned or restricted, to promote individuals' participation in insurance utilizing Insurtech.

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## テレマティクスによる精緻なリスク評価が保険契約者の選択に与える影響 —市場均衡モデルに基づく分析—

諏澤 吉彦

### 要旨

本稿は、インシュアテックの試みの一つとして試行されている、テレマティクスによる精緻なリスク評価が、保険契約者の選択にどのような影響を及ぼすのかを、標準的な保険市場の分離均衡モデルに基づいて明らかにしようとしたものである。テレマティクスによる被保険者のリスク評価の精緻化は、逆選択やモラルハザードの緩和により、保険市場の効率性を向上させることが期待される。しかし実際には、テレマティクスを用いても完全なリスク評価は現在のところ不可能であり、低リスク者から高リスク者への一定の保険料内部補助が残存すると考えられる。分離均衡モデルに基づく分析結果からは、内部補助要素が期待損失に対して定率で保険料に算入された場合に、高リスク者は十分な保障を伴う全部保険を選択するのに対して、低リスク者は一部保険を愛好し、それが高率となれば、過小な保障を伴う保険契約しか選択しないおそれがあることが明らかとなった。いっぽうで、内部補助要素が定額で保険料に算入された場合には、その金額に関わらず、高リスク者、低リスク者ともに、全部保険が選択されることがわかった。

キーワード：インシュアテック、テレマティクス、リスク評価、分離均衡モデル、保険料内部補助

